



Travel Time Budget – Decomposition of the Worldwide Mean

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**TRAVEL TIME BUDGET – DECOMPOSITION OF THE
WORLDWIDE MEAN**

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ABSTRACT

The individual mean travel time budget (TTB) has been hypothesised by Zahavi (1979) as a constant amount of time close to 1 hour per day. This TTB seems to be stable between different cities and between different time periods.

Under the TTB stability hypothesis, travel time-savings are totally reinvested in transport. This reinvestment mechanism could then explain the urban sprawl, and give to the increased speeds all the responsibilities of the “urban transport diseases”.

However, the TTB stability seems to be valid at the world aggregate level only. The paper proposes to explore finer scales of observation of the TTB: from the aggregate to the disaggregated levels of observation. First, a worldwide comparison of 100 cities is produced. Second a hazard based model for the TTB of the French city of Lyon is constructed.

Hence, two opposite urban models appear: an extensive urban model of which development is based on extensive consumption of space and time resources, and an intensive urban model restricting its spatial and temporal extension.

At the disaggregated level, the analysis identifies the relationships between the individual TTB and the socio-economic variables and the mobility and activities attributes. Finally, the model seems to indicate that the traditional hypothesis of the minimisation of the temporal costs of travel is unsuitable for the whole urban population.

Keywords: Travel Time Budget; Aggregated and disaggregated analysis; Travel time minimisation; Duration model.

INTRODUCTION

Facing the management of the increasing mobility, transport policy call for an understanding and quantification of the travel behaviour and the traveller's responses to changes of travel environment. The exploration of new levers on travel behaviour requires to understand the motivation of the travel choices in terms of mean of transport (modes, routes, etc.) and in terms of destination and activity pursued at destination. It leads to the recognition of travel demand as a derived demand. The trips are made in order to engage in activities at different locations (Jones et al., 1983). Travel can be considered both, as one of many attributes of an activity, and/or as an activity interacting with others.

One of the first author to introduce time in transport economics model is Yacov Zahavi, researcher for the World Bank in the 80s. The basis of his model stands on the hypothesis that individual allocate time to travel and non-travel activities. He analyses the TTB for several cities in the world and observes a relative stability in the mean daily time allocated to travel. Then, he assumes that daily times allocated to travel, through the competition between travel and others activities, are stable and do not depend on the other activities (Zahavi, 1979).

A lot of authors have adopted an opposite direction (Purvis, 1994; Levinson and Kumar, 1995; Kumar and Levinson, 1995; Godard, 1981; Van der Hoorn, 1979; Landrock, 1981; Gordon, et al., 1991; Kitamura, et al., 1992). The critics of Zahavi's conjecture have been concerned with the multiple influences of some socio-economic, activity-related and area specific variables. For examples, variables such as income, car-ownership, age, timing of the trips or urban density are shown to influence the TTB. These multiple critiques are warnings to the abusive application of the constant TTB concept in a non-world level.

A key question of the TTB is its level of observation and application. The stability hypothesis is formulated for the world level, but most of the critiques are at disaggregated level such as national, regional or urban level. At these levels, it is clear that the stability is not a valid hypothesis. Then, only regularities in relationship between TTB and variables could constitute a "weak" hypothesis on TTB (Goodwin, 1981).

The paper will explore two levels of observation of the TTBs. First, in the search for regularities in TTB at an aggregate level, we propose to analyse the TTBs at world and continental levels. The UITP's database contains aggregate travel data for 100 cities for 1995 and gives us the opportunity to test the hypothesis of TTB stability. Our analysis supports Zahavi's hypothesis at a world-wide aggregate level, but it reveals two contrasting urban organisations with distinct TTB dynamics. This opposition is based on contrasts that relate to space, time and speed.

Second, to engage in understanding the TTB in the context of the individual time allocation behaviour, we propose to examine the TTBs at the urban level of the city of Lyon (France). The application of a survival analysis reveals the influent variables on TTB and the dynamics of the daily travel times. This method permits to model the conditional probability of ending travel given it has lasted to a specific time. The observed conditional probability is non-monotonic and then does not support the constancy, nor the minimisation of travel times. Furthermore, this probability seems to reveal that daily TTB is weakly affected by the others activities duration.

I. ZAHAVI'S HYPOTHESIS AND REINVESTMENT OF TRAVEL TIME SAVINGS

A. STABILITY OR REGULARITY – “STRONG” AND “WEAK” HYPOTHESES

In the 70s, Zahavi studied travel time and money expenditures. Following the first scholars who suggest the stability of the travel time and/or money expenditures (Tanner, 1961, Szalai, 1972). He claims hypothesis on the “Travel Time Budget” and the “Travel Monetary Budget”. Here we only concentrate on the time resource.

First, at the world level, the TTB constancy hypothesis can be named the “strong TTB hypothesis”. It states that at an aggregate level, the mean TTBs are similar for different cities and for different times (Zahavi, 1979). Second, at the disaggregate (local) level, travel expenditures exhibit regularities, that are assumed to be transferable in different cities and at different times (Zahavi and Ryan, 1980 ; Zahavi and Talvitie, 1980). This “weak TTB hypothesis” supposes only regularities of relationships between TTB and others variables. This distinction leads to the corresponding definitions by Goodwin (1981) of travel “expenditures” rationally determined and predictable quantities and “budgets” which are constant expenditure, such as the allocation of time resource to travel would not be influenced by policy, trends or costs.

These regularities mean that an individual's travel expenditure can be considered as a budget which is rationally determined. Zahavi was one of the first authors to suggest the expenditure budgets concept and to incorporate time budgets in the optimisation program for individual travel choices. In the UMOT (Unified Mechanism of Travel, 1979) model, predictions of travel expenditures are based on the “weak TTB hypothesis” of regularities in relationships between the time and money expenditures and variables, such as speed or the number of household members. Both TTB and TMB appear as budget constraints in the UMOT model. Zahavi reduces the problem of the allocation of resources to transportation to the simple problem of the distribution of fixed amounts of temporal and monetary resources between the different modes of transport.

More precisely, the “strong hypothesis” of the double constancy of travel budgets is defined in the UMOT as:

- The average TTB for a city is calculated on the basis of the average *individual daily duration* of travel for the entire *mobile population*.
- The average TMB for a city is calculated on the basis of the average *available household income* that is spent on travel during one year by all the *mobile households* in the city.
- The two average travel budgets are constant over time for each city. The average travel budgets are similar for all cities in the world.

So, according to Zahavi, this constancy is spatially and temporarily transferable.

Here, we will focus on the TTB parts of the “strong” and the “weak” hypotheses.

B. SYSTEMATIC REINVESTMENT OF TRAVEL TIME SAVINGS

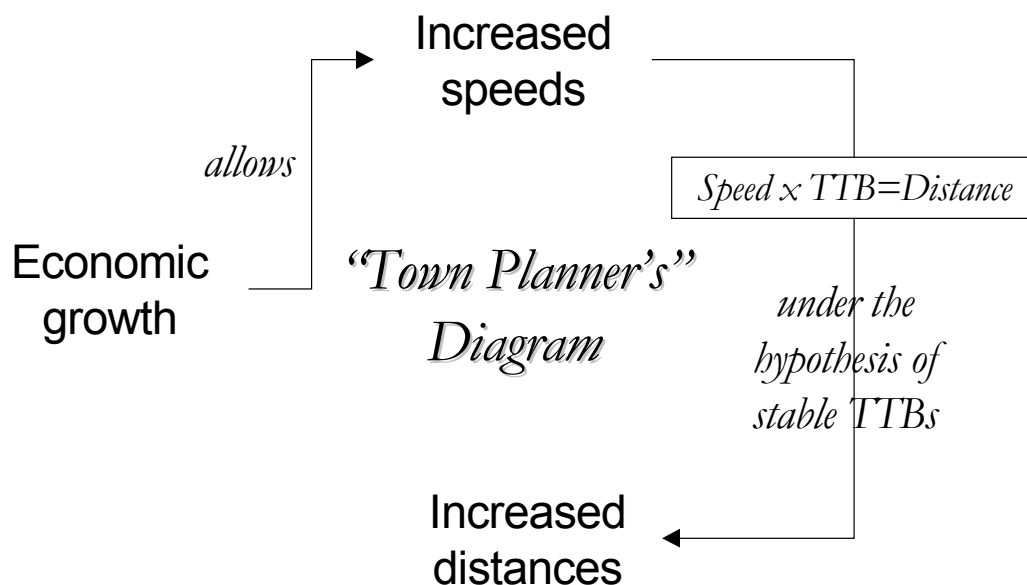
Zahavi describes the mechanism by which an individual acquiring higher speed gains access to new opportunities. A reduction in the temporal cost of transport allows the individual to extend space-time accessibility (Hägerstrand, 1970). The trade-off is

therefore between time savings and accessibility improvements. The hypothesis of stable TTB means that the result of this choice favours increases in accessibility. By deciding to reinvest all his/her travel time savings in additional travel, the individual chooses to extend the space-time prism of his activities. This extension results in either performing the same activities more frequently or at more distant locations or adding new activities to his/her timetable. In all these cases, the individual travels a greater daily distance.

Because of the simplicity with which this hypothesis allows us to characterize the mechanisms involved in the economics of personal travel, it reveals an important characteristic of time: it cannot be stored. This is the origin of the reinvestment mechanism and the apparently paradoxical manner in which this scarce resource is managed. Once speed improvements become possible, it is not possible to store the time saved, it must be consumed in one way or another, and for this consumption to provide its beneficiary with the impression that he is making a genuine gain, it is more than likely that it will lead to new trips, for the simple reason that these involve new activities whose marginal utility is greater than those already performed (work, time at home, etc.).

Under the hypothesis of stable TTB, economic growth leads, as a result of technological progress or an improvement in transport systems for example, to an increase in speeds which relaxes the temporal constraint on travel. The correlation observed between TTB stability and increasing speeds and distances is considered as a causality. This classical reinvestment mechanism can be summarized in what we shall refer to as the “town planner’s diagram”.

Diagram 1: The “town planner’s diagram”



Thus, under Zahavi’s hypothesis, speed and any policy that aims to improve traffic conditions are entirely to blame for the increase in travel and its externalities such as urban sprawl, pollution and energy consumption.

Can this causality, which is defined for an average city which is representative of any city in the world, be applied to explain the urban forms and travel behaviours which are present in the world’s cities?

These are questions that we will try to answer. The next two parts will be based on the “Millenium Cities” UITP’s database, from J. Kenworthy and F. Laube. The UITP’s database provides rare information on daily travel behaviours in the world’s major cities. The database can be used to analyse information that relates to individual travel behaviours with reference to the characteristics of the cities and their transport system. The collected data relate to the demography, the economy, the urban structure, the transport system, and travel behaviours in the cities¹. The first part will update the knowledge the TTB level for 1995 at the world level. The second will define two clearly distinct urban profiles with distinct TTB dynamics.

II. THE “STRONG” TTB HYPOTHESIS AT THE WORLD LEVEL IN 1995

Schafer (2000) and Schafer and Victor (2000) gather numerous data on the mean TTBs at national level and city level. It permits them to verify the stability of mean TTBs in space and time. Then, they predict the future world mobility on the basis of the TTB stability around one hour and prediction of the increase in speed for 2050. Relatively small differences appear in the mean TTB levels obtained because of the divergent methods and definitions used. The mean TTB of Zahavi (1 hour) is defined on the mobile population and only for motorised modes of transport, while Schafer (1.1 hour) studies the entire population and all modes. Nevertheless, the range of their TTBs and the dispersions around the mean are similar.

Available data are composed of the means of characteristics of urban daily individual mobility and attributes of transport systems and urban structure, for each city. For example, it produces the daily number of trips, the daily travelled distances and the daily travel times for motorised public and private transport modes². The tables 1 and 2 illustrate the obtained daily TTBs³ and distances.

Tables 1, 2 and 3: Descriptive statistics for daily motorised TTB, daily travelled distances and modal shares.

Table 1: TTB (in min)	Mean	Standard Error	Ratio Standard error / Mean (%)
Western Europe	43.65	8.56	19.62
France	42,34	5,09	12.02
Oceania	52.39	7.43	14.18
USA and Canada	56.31	13.83	24.57
Asian Metropolis	44.85	6.60	14.73
Emergent nations	41.17	19.84	48.19
Developed nations	47.71	11.23	23.54
World	45.32	15,19	33.52

¹ 175 indicators, relating to 1995, are available for 100 cities in the world. All the continents are represented, as are the different sizes of city from Graz (240,000 inhabitants) to the Metropolitan District of Tokyo (32.3 million inhabitants). Our analysis has concentrated on the 60 cities located in developed countries.

² Walking travel times are not available. Consequently, our analysis is restricted to the motorised trips.

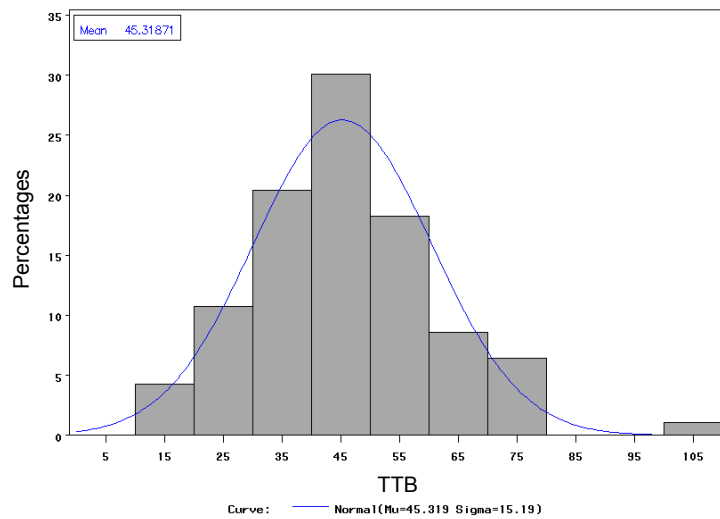
³ Daily travel times for each motorised mode are the product of the number of trips and the daily travel time. Then, the daily TTB is the sum on all the modes of the travel times by mode.

Table 2: Distance (in km)	Mean	Standard Error	Ratio Standard error / Mean (%)
Western Europe	21.62	4.80	22.20
France	18,94	2,96	15.59
Oceania	32.92	5.62	17.08
USA and Canada	42.58	14.60	34.28
Asian Metropolis	22,49	5,33	23.70
Emergent nations	14.23	6.42	45.10
Developed nations	28.21	12.46	44.19
World	23,08	12,59	54.54

Table 3: Modal Shares (% on mechanised trips)	Public transport		Private transport	
	Mean	Standard Error	Mean	Standard Error
Western Europe	25.43	7.96	67.92	10.02
France	18.05	6.10	80.09	5.79
Oceania	5.99	2.41	91.94	1.71
USA and Canada	5.87	4.56	93.19	4.64
Asian Metropolis	42.28	17.38	48.14	13.70
Emergent nations	43.23	20.46	48.91	21.12
Developed nations	20.24	13.81	74.70	16.65
World	28.95	19.99	64.93	22.26

TTBs are grouped in an interval of 15 minutes (41min to 56min). Travelled distances are more dispersed, from 14km to 42km. TTB's standard errors are large, near 10 minutes and represent 12% to 48% of the mean. In the both aggregated cases of the world mean and the developed nations mean, the dispersion is greater than in each sub-group of cities. Figure 2 presents the daily TTBs histogram, with the estimated normal distribution. The dispersion is symmetric and relatively concentrated around the mean. The dispersion is near the Zahavi's or Schafer ones. Most of the TTBs are contained in an interval of around 40 minutes of range. And standard error represents 34% of the mean (Zahavi obtained standard error near 50%). Our first results do not reject the stability of the TTBs as defined by Zahavi and Schafer.

Figure 1: Distribution of the world TTB



Nevertheless, given the observed dispersion, one can suspect that the world mean masks variety of situations. The tables 1 and 2 can be used to establish two groups of city of the developed nations. These groups can be distinguished by their space and time consumption for travel. The Western European cities and the Asian metropolises are characterised by TTBs around 43 minutes and travelled distances closed to 21km. The North American developed cities and the Oceanic cities show extensive consumption of time and space for travel, with 55 minutes TTBs and 40km distances. These cities constitutes the *extensive urban model*. By opposition, the Western European and Asian cities constitutes the *intensive urban model*.

This opposition seems to be valid in terms of modal shares. The extensive cities show high car-dependency (around 90%) and reduced public transport modal share (5%). In the intensive cities, the public transport systems represent 20% in Western Europe and 40% in Asian metropolises.

The next part presents the first level of decomposition of the level of observation of TTBs: the continental level. At this level, one can suspect the TTBs of different regions not to be equivalent. Furthermore, it will not be surprising to find significant influent variables on the TTB, as shown for example, by Levinson, Wu and Rafferty (2003) in the USA. They show significant effects of congestion, income, population, population density and area.

III. UNDER THE WORLD AGGREGATE LEVEL

On the basis of the same but older data, the opposition of cities group is also observed by Newman and Kenworthy (1989) and Kenworthy and Laube (1999), with respect to urban morphologies and transport systems characteristics. The first study claims that urban density is the way toward sustainable mobility, reduced energy consumption and reduced pollution emissions. With the 1995 UITP's data, we observe equivalence between our cities groups, based on time and space consumption for travel and the groups defined by Newman and Kenworthy or Kenworthy and Laube.

A. THE SPACES OF TRAVEL

With regard to travel, a city can be described in terms of its urban organization and transport system. The geographical organization of the city provides a framework which influences travel behaviour, both as regards the spatial dispersion of socioeconomic opportunities and as regards travel conditions. The transport system provides a set of travel methods each of which can be defined by monetary and temporal costs and accessibilities.

a. Urban structure

Analysis of the “geography” of the cities reveals contrasting urban morphologies. Thus, the extensive model, which applies in the cities of North America and Oceania, is, on average, characterized by lower density and higher surface area and population than the intensive model which applies in Western Europe and Asian metropolises.

The results as regards urban densities reveal a clear contrast: intensive cities are far denser. They manage space more intensively by concentrating jobs and housing. But density also affects the organization of the city’s road system.

Figure 2: General indicators depending on the type of urban organisation

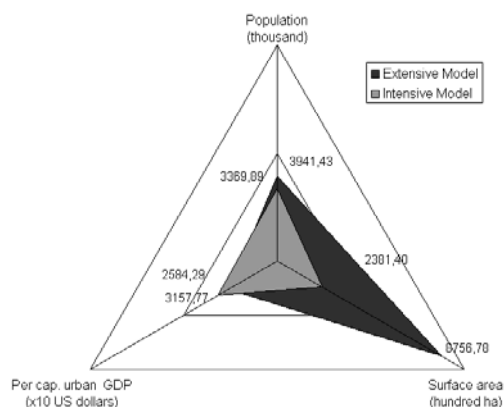
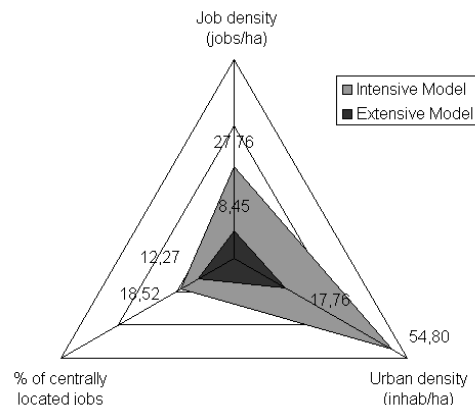


Figure 3: Urban density indicators depending on the type of urban organisation



The relative wealth of extensive cities in spatial terms is certainly partly explained by geographical (topographic) constraints acting on the city. But the history of the transport modes which permitted its development must also be considered. Furthermore, the different urban morphologies and contrasting dispersion of socioeconomic opportunities leads one to think that distinct travel needs will result

from the different types of organization. Consequently, the transport systems which meet these needs are likely to be oriented differently.

b. The transport systems

As we saw, the extensive model is very strongly marked by dependency on car. In these cities, the car has a market share of 92.88%. Whereas, public transport and the use of non-motorized modes tend to be preserved in intensive cities and together account for one third of trips. The individual choices which underlie modal split are partly explained by the relative cost of transport; the cost of car travel is lower in extensive cities than in intensive cities.

Figure 4: Use of motorised transport modes according to the type of urban organisation

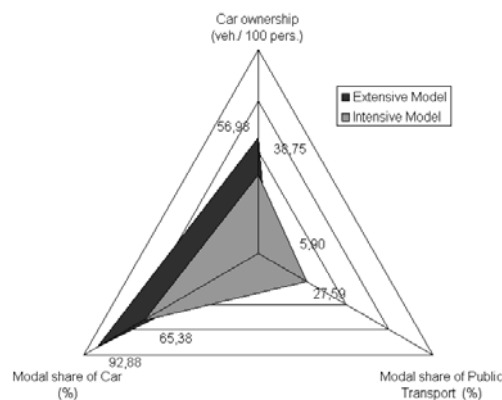
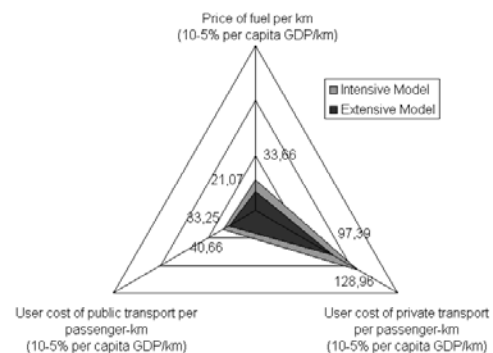


Figure 5: User cost of motorised transport modes according to the type of urban organisation



B. TRAVEL TIMES - CONTRASTING TRAVEL BEHAVIOURS

This contrast between different models of urban organization is accentuated by the observed differences in travel behaviour. In spite of higher speeds, TTBs are higher in the extensive model. In these cities, it is as though increased incomes provide higher speeds and require greater distances. The orientation of the transport system towards the car, which is made possible by higher income, does not seem to save time (figure 8). In spite of the relative efficiency of the extensive model in terms of speed, due to higher motorization level, these cities experience spatial and temporal expansion.

Figure 6: Travel indicators according to the model of urban organisation

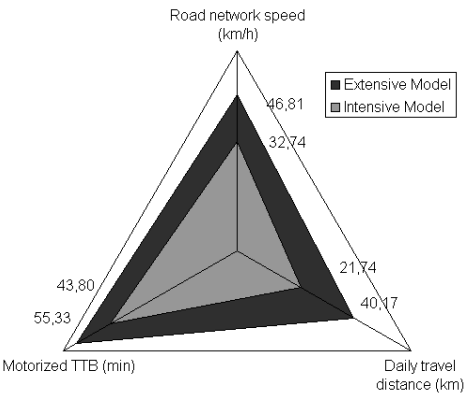


Figure 7: Travel indicators according to the model of urban organisation

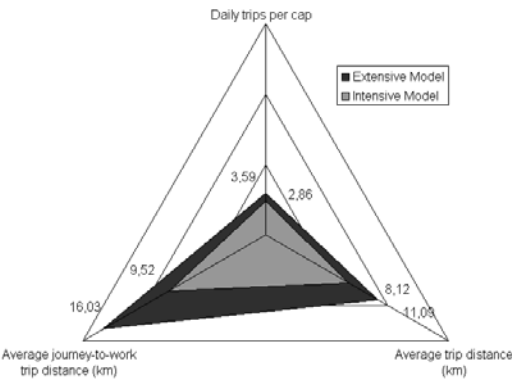
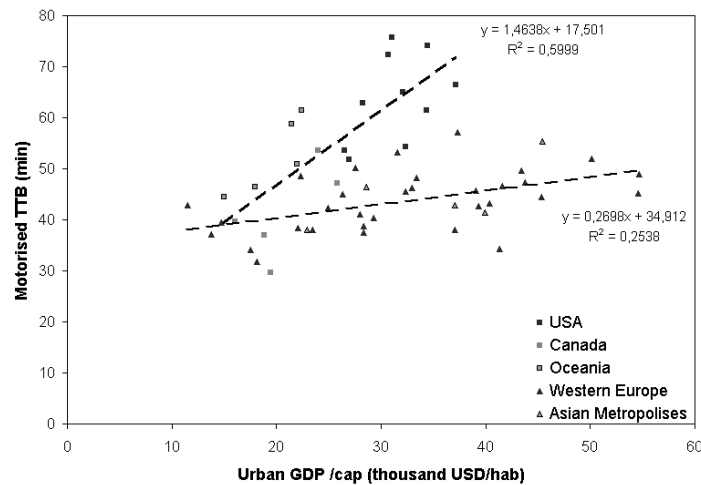


Figure 8: Motorised TTBs per person (in minutes) and per capita urban GDP (in thousand US dollars) in Western Europe, North America, Oceania and Asian metropolises.



The urban GDP can be viewed as an indicator of the city level of development or as an indicator of the population wealth. In this two context, it appears that it affects positively and significantly the TTB of the extensive cities group.

Then, at the “continental” level of observation, TTB do not appear to be similar in space. In the relatively narrow interval of the world TTBs, we observe distinct groups of cities with different time and space consumption. Furthermore, we have shown in July (2004), that numerous variables affect the TTBs. A multiple regression analysis and a principal component analysis are performed to study the differences between the two groups of cities and to enlighten the influent variables on TTBs. Those variables are relative to the urban structure, the system of transports, and to the mobility characteristics. And specific effects are observed between the two urban models.

Consequently we can not confirm the “strong hypothesis” of TTBs stability at finer scale than the world level. In addition, we observe a paradoxical use of speed and travel time savings. Despite a clear speed advantage, extensive cities show higher TTB than intensive cities. The distances travelled exceed what can be achieved with a TTB of one hour.

The extensive city model not only invalidates the transferability of Zahavi’s conjecture to any level less aggregated than the whole world, it also casts doubt on the causal link between speeds, TTB and travel distances. Although TTBs lose their role of maintaining travel levels constant, speeds retain their ability to generate travel. Increased levels of travel, which according to Zahavi’s conjecture, could simply be a linear projection of speed gains could, in the case of the extensive model, be exponential.

Furthermore, the increase of TTBs with speed, leads us to question the way individuals determined their travel times. In the competition for the limited temporal resource, travel times are generally considered by transport economists as a cost to be minimised. In this context, the increase of TTBs is counterintuitive.

IV. THE DESAGGRAGATED LEVEL – THE CITY OF LYON (FRANCE)

To analyse the way individuals manage their temporal resource allocated to travel, we will analyse the daily travel times at the individual level. This will be done with the household mobility survey conducted between November 1994 and April 1995 by the CERTU (Centre d'Etudes sur les Réseaux, les Transports, l'Urbanisme et les constructions publiques) in the French agglomeration of Lyon. The survey collects data on socio-demographic and mobility characteristics of the 6000 households and of each individual in the household. The survey also includes information on a week day mobility of all members of the household above 5 years of age. Each trip is described by (a) the starting and stopping times, (b) the types of activities at origin and at destination, (c) the travel mode. Thus, the one-day out-of-home activity diary can be deduced, from the first trip to the last trip of the day.

Table 4 presents the summary statistics. The mean TTB is near the TTB obtained by both Zahavi and Schafer. Here, travellers with TTB greater than 6 hours (less than 1% of the sample) or out of the urban area (less than 5% of the sample) can not be assimilated to the representative daily urban traveller and then are excluded from the analysis or their TTB are considered as censored duration.

Table 4 : Summary statistics of TTBs (in min)

Mean	76.5	Median	65	Interquartile Range	60	Quantile 75% (Q3)	100
Standard error	51.74	Mode	60	Range	353	Quantile 25% (Q1)	40

To perform a multidimensionnal analysis of the TTBs the duration model methodology is applied. First, this technique is suitable to deal with duration data that are non-negative and that can be censored⁴ and time-varying. The linear classical methods are irrelevant to model positive variables or partially observed or measured variables. Furthermore the qualitative models as the logistic regression integrate not easily variables that could change during the observation period (Allison, 1995). Second, the duration model introduces the duration dependence concept. It models the conditional probability of the end-of-duration of a process, given that it has lasted to a specified time, and permits the likelihood of ending to be depending on the length of elapsed time. Hence, this probability can vary during the process.

Used in biometrics and industrial engineering fields, the duration models have been applied in transportation fields in multiple ways: accident analysis (Jovanis and Chang, 1989 ; Mannering, 1993, Nam and Mannering, 2000), car ownership (Mannering and Winston, 1991 ; Gilbert, 1992 ; Hensher, 1998), traffic queuing (Paselk and Mannering, 1993), duration before acceptance of a new toll (Hensher and Raimond, 1992), and traveler's activity behaviour. The analysis of the activity behaviour focus on: the time spent at home between trip generating activities (Hamed and Mannering, 1993 ; Mannering et al., 1994 ; Misra and Bhat, 2000) ; the duration of out-of-home activities (Niemer and Morita, 1996 ; Kitamura et al., 1997 ; Bhat, 1996a,b ; Timmermans et al., 2002) ; the duration between two occurrences of an activity (Schonfelder and Axhausen, 2000 ; Bhat et al., 2002). Hensher and

⁴ The observation of an process is censored when its beginning (left censored) or its end (right censored) are excluded from the observation period.

Manning (1994) and Bhat (2000) present detailed overviews of the existing applications of duration models in transportation field.

Finally, the modelled conditional probability can question the TTB stability hypothesis and the minimisation of the temporal component of travel costs. Indeed, the estimation of this conditional probability, named hazard rate, will inform us on the temporal dynamics of TTB. Then, increase of this probability in elapsed time will imply accelerated decrease of estimated TTB. Given TTB stability around 1 hour, the hazard should increase faster after 1 hour of elapsed time in transport. Hence, given the minimisation of travel time expenditure, we should observe, at least, a monotonically increasing hazard with elapsed time.

A. OVERVIEW OF DURATION MODELS

In the duration model framework the hazard function, $h(t)$, is the conditional probability of the non negative variable, T , which represents the duration of the process. Then $h(t)$ is the instantaneous probability that the process ends in an infinitesimal interval Δ after time t , given that this process has lasted to the time t . The hazard function is given by:

$$h(t) = \lim_{\Delta \rightarrow 0^+} \frac{P(t \leq T < t + \Delta / T > t)}{\Delta}$$

This conditional probability can be expressed in terms of the density, $f(t)$, and cumulative density, $F(t)$, functions of T .

$$f(t) = \lim_{\Delta \rightarrow 0^+} \frac{P(t \leq T < t + \Delta)}{\Delta}$$

$$F(t) = P(T < t) = \int_0^t f(u) du$$

Then the probability of end-of-duration in an infinitesimal interval of range Δ , after t is given by: $f(t) * \Delta$. The probability that the process lasts to time t is $1 - F(t)$. Hence, the hazard function can be written as:

$$h(t) = \frac{f(t)}{1 - F(t)} = \frac{f(t)}{S(t)},$$

where the complementary probability of $F(t)$ is $S(t)$, the survival distribution (probability to survive until t or the endurance probability, Bhat, 2000):

$$S(t) = \Pr[T \geq t] = 1 - F(t)$$

The hazard and the survival functions describe the duration process. So the shape of the hazard function has important implications for the duration dynamics.

To study this shape, one may use three approaches: parametric, non-parametric and semi-parametric estimations.

Non-parametric approach

The non-parametric approach is similar to an exploratory data analysis. The survival function is estimated using the Kaplan-Meier product limit estimator (Kaplan and Meier, 1958). The KM estimator of survival at time t_j is computed as the product of the conditional survival proportions:

$$S_{KM}(t_j) = \prod_{k=1}^j \frac{r(t_k) - d(t_k)}{r(t_k)},$$

where $r(t_k)$ is the total population at risk for ending at time t_k . $d(t_k)$ is the number of individuals stopping at t_k . The life-table method is applied. It groups event times into arbitrary determined intervals and assumes a constant hazard within each interval. Here, for the TTB of Lyon, times are rounded to the nearest 5 minutes, then a width of 5 minutes is believed to be the suitable interval. The estimation of the hazard and the survivor functions characterising the distribution of the duration variable, T , will be given at the midpoint of the interval. This approach produces an empirical approximation of survival and hazard, but hardly models effect of covariates.

Parametric approach

The incorporation of the effect of covariates can be done through two parametric forms: the proportional hazards form and the accelerated lifetime form. The first form assumes a multiplicative effect of covariates on a baseline hazard function. In the second form, a direct effect on duration is assumed.

- Proportional hazard model

The proportional hazard model (PH model) assumes that the hazard function is decomposed as:

$$h(t/X) = h_0(t) \cdot g_0(X) = h_0(t) \cdot \exp(-\beta X),$$

where $h_0(t)$ is the baseline hazard. $h_0(t)$ is a function of survival time and represents the duration dependence, i.e. the variation of the probability of ending in time. $g_0(\cdot)$ is a function of the covariates and gives the change of the hazard function caused by the covariates. The separation of the time effect and the covariates effects leads the PH model to assume the proportionality between the hazard rates of two individuals, i and j , with different attributes. Given that the covariates effects are not time dependent, the hazard ratio is given by:

$$\frac{h_i(t)}{h_j(t)} = \exp\{\beta_1(x_{j1} - x_{i1}) + \dots + \beta_k(x_{jk} - x_{ik})\},$$

The distributional assumptions for the baseline hazard $h_0(t)$, impose specific forms to the shape of the hazard function: constant, monotone or U-form. The estimation will conduct to the distributional parameters and covariates estimators.

- The accelerated lifetime model

The second parametric form permits the covariates to affect the duration dependence. Then, it assumes that the covariates act directly on time. The survival function in the ALT model is:

$$S(t / X) = S_0[t \exp(-\beta X)],$$

where $S_0(t)$ is baseline survivor function. Furthermore, corresponding hazard function is:

$$h(t / X) = \frac{-\partial S(t / X) / \partial t}{S(t / X)} = h_0[t \exp(-\beta^* X)] \cdot \exp(-\beta^* X)$$

The ALT model can be expressed as a log-linear model, such that $\ln t = \beta' X + \varepsilon$, with density function of the error term $f(\varepsilon)$, that differs according to the type of estimated model.

In the two parametric approaches, there exist a need to specify the used distribution function. The classically used distributions for duration distributions are the exponential, Weibull, log-logistic, Gompertz, log-normal, gamma, and generalised

gamma distributions. Validity of the exponential and Weibull distributions can be graphically tested in the non-parametric approach⁵.

The parametric approaches permit simultaneous estimation of covariates effects and of duration dependence. However, the distributional assumption for the baseline hazard is risky. Meyer (1990) has shown that the parametric approach inconsistently estimates the baseline hazard when the assumed parametric form is incorrect.

Semi-parametric approach

Finally the semi-parametric approach focuses solely on the covariates coefficient estimates. This estimation technique estimates the PH model using the partial likelihood framework suggested by Cox (1972), which do not need the specification of the baseline hazard function, $h_0(t)$. One avoids then the risk of a mis-specified baseline function. The quality of the estimation of the covariates coefficients is considered to be more robust than the fully-parametric approach (Oakes, 1977). But the Cox model excludes the baseline hazard and does not allow for consideration of the duration dependence.

B. RESULTS

Non-parametric estimation

Life table method constitutes first exploration of the distribution to be used in the parametric approach.

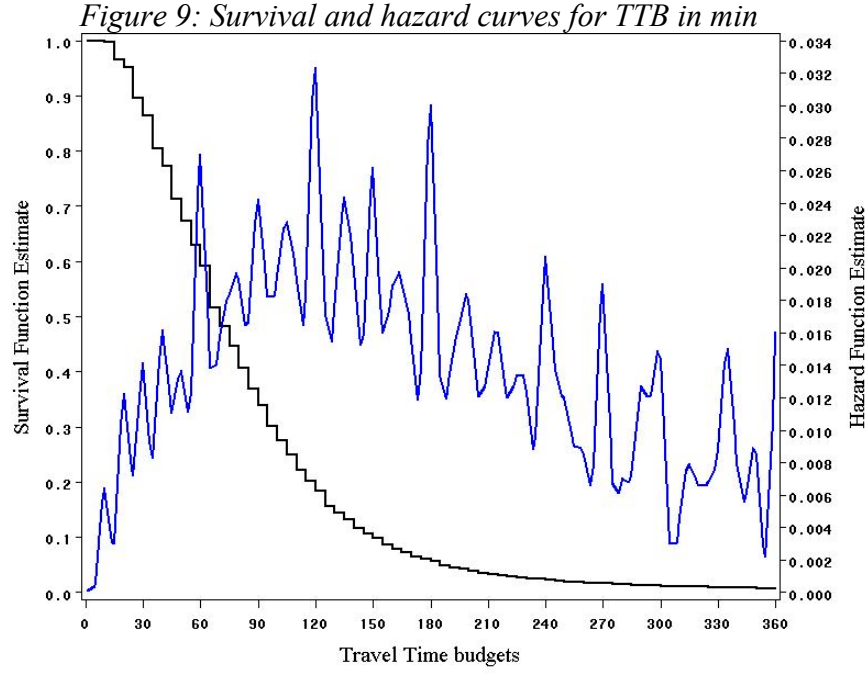
The resulting survival and hazard functions are presented in figure 1. The survival curve presents two inflexion points. The first, near 20 minutes, seems to indicate the existence of minimum TTB level of 20 minutes, that is, declared by almost all travellers. The second point, near 110 minutes corresponds to a diminishing probability of the ending after 2 hours of travel. The survival decreases at a decreasing rate.

The hazard curve is characterised by peaks for 1, 2 and 3 hours that result from the rounding of declared travel times. The hazard curve presents clearly a point where the slope is reversed. The hazard is increasing until near 110 minutes, and then decreasing.

⁵ If the hazard is constant ($h(t) = \lambda$) then : $-\log S(t) = \int_0^t h(u) du = \lambda t$.

This implies that a plot of $-\log \hat{S}(t)$ against t should be a straight-line through the origin.

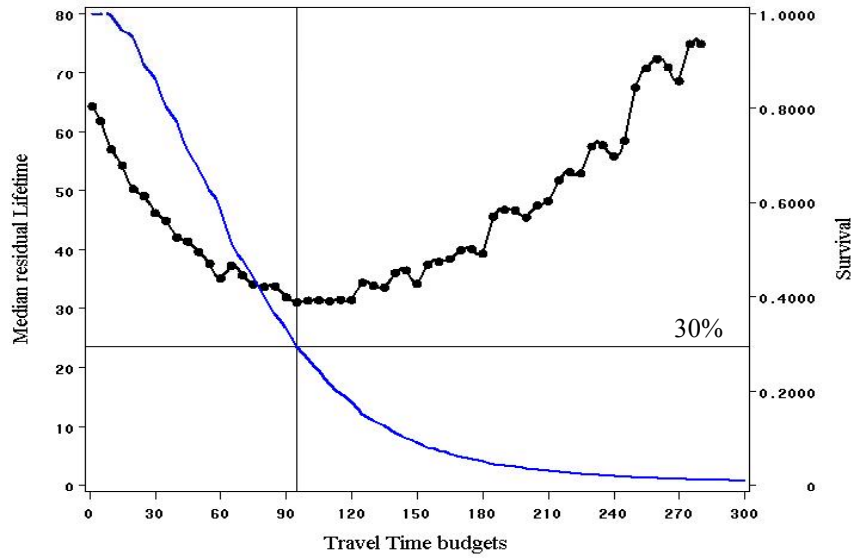
And the plot of $\log[-\log \hat{S}(t)]$ against $\log(t)$ tests the Weibull distribution. In this case, the hazard is $\log h(t) = \alpha + \beta \log t$. Hence, a plot of $\log[-\log \hat{S}(t)]$ against $\log(t)$ should be a straight-line with β slope.



The non-monotonic form of the hazard curve suggests that non-monotonic distributions (log-logistic and log-normal) will be appropriate distributions in a fully-parametric model. Furthermore, the graphical test of linearity of the transformations ($-\text{Log}(\hat{S})$ and $\text{Log}[-\text{Log}(\hat{S})]$), rejects the hypothesis of exponential and Weibull distributions.

The median survival times (or median residual lifetimes) are presented in figure 2. For each time t , it approaches the expected survival time given that the process has lasted to t . For a null TTB, the median survival time is 65 minutes, near the Zahavi's TTB level. The decreasing part of the curve suggests that travellers reduce the travel times during the first hour. But from 90 to 120 minutes, the median survival time is stable. Then, individuals that have already a 1.5 hour TTB, are expected to pass 30 minutes more in travel. And finally the median survival time is increasing after 130 minutes. The population concerned with the non-decreasing median residual lifetime is about 30% of the sample.

Figure 10: Median residual lifetime



The hazard rate and the median survival time suggest a transition in the allocation of time to transportation, near the 90 minutes level. Everything happens as if, after this level, the travellers failed to diminish their travel times. Therefore, one can segment the population. First, a group of individuals who minimise travel times and that is characterised by a near 1 hour TTB. Second, a group of travellers that abandon, or can not achieved the minimisation of travel times.

Parametric estimation⁶

Classically, applied duration models to duration activity have used Weibull distribution function (Mannering et al., 1994; Kitamura et al., 1997). This distribution corresponds to a monotonic hazard, which in our case is not observed. The non-parametric approach concludes to a non-monotonic hazard function and rejects exponential and Weibull distribution functions. Then, the accelerated lifetime models with the log-normal and log-logistic distributions are estimated. The log-logistic model produces the best likelihood and residuals⁷. Then, only the estimates of covariates for the log-logistic model is presented in Table 5.

Most of the covariates are significant at 5%. The model is constructed with 3 different sets of covariates. First, the set M1 contains only individual and household covariates. The age covariates is non-significant with a near zero estimate. In an accelerated lifetime model, estimates can be interpreted in terms of expected time ratio. For example, the expected TTB of men is 9% greater than the expected TTB of women. The older are characterised by a 11% lower TTB. The professional status affects the travel duration. Hence, worker (full time, part time workers and students) have higher TTB. And Scholar have lower TTB. The household responsibilities, represented by the number of children leads to lower TTB. And the number of

⁶ The semi-parametric estimation has been performed and has produced estimates of the covariates in similar sense than the parametric estimation which permits to estimate the duration dependence by imposition of a distribution function.

⁷ In general, likelihood-ratio statistics can be used to compare models, those are nested within another. The exponential, Weibull and log-normal models are special cases of the generalised gamma model, and can then be compared. But the log-logistic is not nested within the generalised gamma distribution. Then, we can only compare the goodness-of-fit of the log-normal and log-logistic model with likelihood level and residuals of Cox-Snell.

household members increases the TTB. The members of household characterised by high income have higher TTB. The residential location affects the TTB. The central location decreases TTB, as the 1st and the 3rd ring of the East of Lyon. Finally, the mobility depends on the day of the trips. The TTB on Monday are lower and on Friday are higher. These results are classical findings of the other studies on travel times. At the disaggregated level, the travel times budget can not be constant.

Second the covariates set M2 is composed of the M1 set and the duration of activities: work activity (full time, part time and students), leisure activity (recreational, social out-of-home activity), shopping activity and pick and drop duration. The introduction of these variables improved the likelihood of the model. But their effects on the TTBs are small (less than 0.1%). This result is confirmed by the applications of the other estimation techniques: semi-parametric and non-parametric estimations. Then it may indicate that the daily sum of the travel times is not clearly dependent on the daily sum of the times allocated to the activities. The examination of the competition between activities for the time resources, using the definition of the daily travel time budgets as a whole failed to enlighten relationships between activities times. Whereas, other researches on the allocation of time do not use TTB, but analyses the relationship between the trip travel time or the daily travel time and the corresponding activity. For example, Kitamura et al., (1992), Levinson (1999), Hamed and Mannering, (1993), Timmermans et al., (2002) have estimated linear equations on daily travel duration for the corresponding activity. Structural equations model is applied to the corresponding travel time to each type of activity by Fujii et al. (1997), Golob and McNally (1997), Lu and Pas (1999).

The M3 set introduces the principal modes of transport used for the daily trips⁸. These covariates are highly significant and influent. They clearly are indicators of the accessible speeds. Then, one may suspect strong endogeneity between the mode of transport chosen and the travel time.

Finally, for the three covariates sets, the estimates are stable for the three models. And the scale parameters of the log-logistic distribution are less than unity, corresponding to a non-monotonic hazard with inverted U-shape. The hazard rate in the M3 model is then increasing until 76.8min and decreasing afterwards. Figure 11 shows the hazard rate for the M3 set.

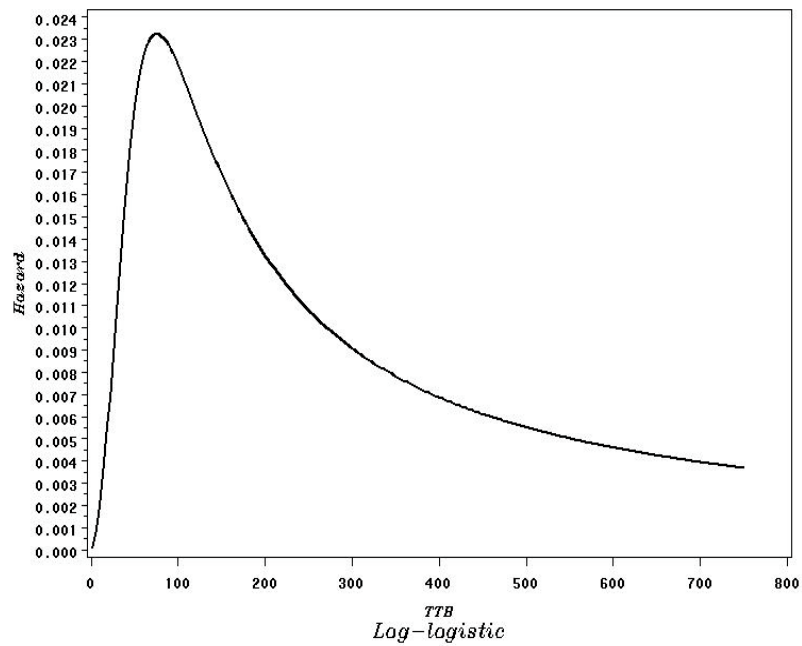
⁸ The principal mode of transport used is defined as the one with the highest corresponding number of trips.

Table 5 : Log-logistic parametric model

Parametric log-logistic distribution	M1: HH and individual variables	M2: M1 + activities duration	M3: M2 + principal mode used
Dependent variables	Estimates	Estimates	Estimates
Intercept	4.01 ***	3.625 ***	3.929 ***
Male	0.091 ***	0.088 ***	0.067 ***
Age over 50 years	-0.118 ***	-0.112 ***	-0.079 ***
Age	0.0006	0.002 **	0.003 ***
Worker	0.148 ***	0.271 ***	0.234 ***
Scholar	-0.215 ***	0.018	0.065 **
Number of Children	-0.045 ***	-0.051 ***	-0.019 **
Nb of HH members	0.037 ***	0.052 ***	0.038 ***
High income HH	0.086 ***	0.064 ***	0.052 ***
Central location	0.058 **	0.033	0.036 *
1 st ring East	-0.048 ***	-0.044 **	-0.035 **
3 rd ring East	-0.055 ***	-0.062 ***	-0.067 ***
Monday	-0.096 ***	-0.057 ***	-0.052 ***
Friday	0.057 ***	0.038 **	0.039 **
Work duration		0.0001 ***	0.0001 ***
Leisure duration		0.001 ***	0.002 ***
Shopping duration		0.002 ***	0.002 ***
Pick and Drop duration		0.003 ***	0.004 ***
2 wheels motorised			-0.704 ***
Walking			-0.742 ***
Public transport			0.050 **
Bicycle			-0.282 ***
Car			-0.367 ***
Scale	0.401	0.386	0.362
Log Likelihood	-13136.967	-12697.998	-11942.856

* 0.1, ** 0.05, ***0.01 level of significance

Figure 11: Estimated hazard for log-logistic model



V. CONCLUSION

The Zahavi's hypothesis of the one hour TTB stability between periods and cities is discussed in the first part of the paper. The TTBs of 60 cities from developed countries are compared, with respect to characteristics of the urban structure, the system of transport and mobility indicators. At the world level, the TTB's dispersion is similar to the one obtained by Zahavi or Schafer. But, in the relatively narrow interval of the TTB, two groups of cities can be identified which show distinct time and space consumption. On the one hand, an extensive cities group (North American and Oceanic cities) is characterised by a transport system with extensive travel times and travel distances. On the other hand, the intensive cities group (Western European cities and Asian Metropolises) shows transport systems which restrict their space and time consumption. In each of these groups TTBs are found to be depend on several variables. Finally the link between TTB and speed seems somewhat paradoxical. On the one hand, speed appears to be responsible for the explosion in distances, and reducing speeds would therefore appear to be a way of limiting the spatial expansion of cities. On the other hand, speed fails to reduce TTBs, rather seeming to increase them. The new accessibilities seem to compensate more and more effectively for the disutility of travel time. Thus, a speed reduction policy appears unrealistic and inefficient if TTBs are only flexible upwards. The reinvestment of travel time-savings partly explains travel choices, but in order to understand these fully we must consider the allocation of time to transport at the disaggregated level.

Then, the second part of the paper presents a survival analysis applied to the TTBs of the city of Lyon. The sum of daily travel times is analysed with respect to the non-parametric lifetable approach and the full-parametric approach. The first method gives incentives to use a non-monotonic *a priori* distribution in the full-parametric model. Usual covariates, such as number of children, gender, age, household income, household localisation, employment status, day of trips, are shown to be significant. It shows the irrelevancy of the TTB stability hypothesis in the city of Lyon. The stability will mask the multiple mechanisms acting in the time allocation process. TTBs do not appear clearly dependent on the activities time budgets. But travel times appear related to the corresponding activity type and duration in others studies. Finally, the log-logistic model gives best goodness-of-fit. The estimated log-logistic scale implies a non-monotonic inverted U-shaped hazard, with inflexion point near 75 min. Under TTB stability hypothesis, or more generally under travel time minimisation the hazard rate is expected to be monotonically increasing. The estimated log-logistic hazard seems to show that everything happens as if 2 groups of travellers exist. The behaviour of a first group of individuals can be represented by the minimisation mechanism. A second group is composed of individuals that can not or do not want to minimise their TTB.

To gain robustness, the eventuality of heterogeneity between individuals needs to be included in this study. Furthermore, the application of duration model to the TTB failed to consider transport as a derived demand. Here, the duration of daily transport is disconnected from the pursued activities. Hence, the activity duration should be included in the covariates set. Duration models may offer an appropriate framework to reach the integration of derived demand concept into the allocation of time modelling.

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